Integration of Terrain Image Sensing with UAV Safety Management Protocols

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Abstract. In recent years there has been increased interest in the development of lightweight rotor-based UAV platforms which may be deployed as single or multiple autonomous UAV systems in support of applications such as ground surveillance, search and rescue, environmental monitoring in remote areas, bridge inspection and aerial imaging of crops. With the increased complexity of the UAV platforms comes a legal requirement that any UAV operates in a safe manner and is able to land safely in the presence of control and power when flight task exception conditions are alarmed. No standards currently exist for the in-line discovery and designation of UAV Safe Landing Zones (SLZs) for rotor-based platforms and this paper describes a novel approach which has been developed as part of a wider UAV Safety Management Protocol. Aspects relating to the SLZ sensing, classification and designation are described together with the methodology for deciding on the SLZ attainability.

Key words: Quadrotor UAV, UAV safety management protocol, UAV safe landing zone detection

1 Introduction

For many sensing applications such as monitoring atmospheric pollution or surveillance, Unmanned Aerial Vehicles (UAVs) provide a versatile and often inexpensive method of gathering data. UAVs offer many advantages over manned aircraft the most notable of which is the removal of humans from situations which may be deemed dull, dangerous or dirty. There are a wide range of commercially available UAVs which can be equipped with many types of sensors, for example infra red cameras for oil slick detection [1] or video cameras for traffic monitoring [2].

The Sensing Unmanned Autonomous Aerial Vehicles (SUAAVE) project [3] is concerned with the development of swarms of coordinating 'autonomous' UAVs. The UAVs are autonomous in that low level flight controller commands are generated in response to high level goals, for example GPS waypoints. Currently Ascending Technologies Quadrotor Hummingbird UAVs [4] are used within the

SUAAVE project. These UAVs have a flight time of approximately 23 minutes or 12 minutes with a 200g payload. They have four flexible rotors and can be equipped with a variety of sensors. The Hummingbird UAVs used within the project are currently equipped with a Point Gray Chameleon colour camera, GPS, Inertial Measurement Unit (IMU) and wireless communication capabilities. An initial application scenario for the SUAAVE project is that of mountain search and rescue. In this scenario swarms of collaborating UAVs offer many advantages over a single UAV working in isolation. These include:

1. Heterogeneous sensors - UAVs may be fitted with different types of sensors and their respective actions coordinated based on the data detected by other members of the swarm. For example, a UAV equipped with an IR camera flying at a relatively high altitude may be able to identify heat signatures on the ground. A UAV equipped with a colour camera could subsequently be dispatched to areas which have a high probability of containing the casualty given the observations by the IR camera [5].
2. Efficient searching - One of the most important constraints in a search and rescue scenario is time. By utilizing swarms of coordinating UAVs an area can be searched relatively quickly and efficiently.
3. Robustness against mission failure - In the event of a UAV malfunction a mission can continue to be executed by other members of the swarm.

There are many possible situations which may trigger a UAV malfunction. For the most serious of UAV malfunctions it is desirable to land the UAV as safely and quickly as possible. Such scenarios include prolonged loss of GPS signal, a sudden change in operating conditions resulting in insufficient battery life to navigate to the base station and a loss of communication capabilities.

Presented in this position paper is the current state of work within the SUAAVE project related to the safe operation of the UAVs. A Safety Management Protocol (SMP) is outlined which incorporates a method of autonomously detecting safe landing areas from image sensor data.

The remainder of the paper is structured as follows. In section 2 an overview of related work is presented. Section 3 describes the components of the SMP. An algorithm for the autonomous detection of safe landing sites is outlined in section 4. In section 5 the process of choosing a safe landing site from the available alternatives is discussed. Finally, conclusions and proposed future work are outlined in section 6.

2 Related work

For the most serious scenarios it may be the safest course of action to instruct the UAV to land. These scenarios may be caused by a variety of reasons, for example prolonged loss of GPS signal due to the profile of the terrain [6] or a hardware error.

The definition of a safe landing site varies depending on the UAV's size and type, for example the Ascending Technologies Hummingbird UAV will require a much smaller landing site than a MQ-9 Reaper UAV. However, it is proposed by [7] that a safe landing system should, minimize the expectation of human casualty, minimize external property damage, maximize the chance of aircraft survival and maximize the chance of payload survival. Under certain circumstances it may not be possible to satisfy all of these requirements, for example it may be safer to land the UAV in a lake as opposed to a school yard.

One method of detecting safe landing areas is to create a 3D map of the surrounding terrain. In these approaches a user is required to provide the GPS coordinates of the suitable area. The UAV then navigates to this area and creates a 3D map of the terrain which enables suitable areas, for example flat, smooth surfaces to be identified. This 3D map can be created by a variety of approaches including stereo ranging [8], structure from motion [9] and laser scanning [10].

The work in [10] addresses the issue of the effect of obscurants on safe landing zone identification by utilizing a laser range finder to create a 3D reconstruction of the terrain. Accurate 3D terrain reconstruction is influenced by the position and pose estimation of the UAV at any given time. In this approach the pose measurements are fused with the laser scan using a probabilistic model of pose error and the likelihood of an accurate point in 3D space given 2 successive scans. However [10] found that in some cases the laser beam reflected off smoke resulting in an inaccurate reading of the terrain profile.

Perhaps the main disadvantage of methods which attempt to reconstruct terrain is the required equipment. In [8] a stereo pair of cameras is required. Whilst this may be achieved using two low cost cameras whose pose and relative position is known it increases equipment payload and power consumption. Similarly, the use of a laser range finder as proposed by [10] would be impractical for a small quadrotor UAV.

In the work by [11] the terrain is reconstructed using a single camera. However, in order to achieve this multiple passes of the same area is required. In the scenario of an emergency forced landing this may not be achievable due to limited battery life. A further disadvantage is the requirement of an accurate estimation of camera movement. For a UAV with constantly changing velocity this may be difficult.

An improvement on these approaches in terms of required equipment is presented by [12]. In this work a user chooses a safe landing area via a series of navigation waypoints either from an aerial image or from the live UAV camera feed. The optical flow between two successive images is estimated using Scale Invariant Feature Transform (SIFT) features and used to estimate depth structure information. An assumption is made that areas with low variance between optical flow vectors indicate flat areas and are therefore deemed to be a safe landing site. A threshold for determining the boundaries between safe and unsafe is calculated during a supervised training phase.

Each of the approaches discussed provide a degree of autonomy in that the UAV is able to detect landing sites and land without receiving low level commands from the operator. However many of the systems described require significant human input such as manually identifying suitable landing sites via a

GUI. In the SUAAVE project were an operator is responsible for multiple UAVs it may not be feasible to choose a landing site whilst possibly ignoring the status of other UAVs in the swarm.

3 A safety management protocol

Understandably safety is given utmost priority within the SUAAVE project. An implemented safety management protocol (SMP) defines a set of operational constraints on the UAV platform to help ensure that a mission is executed as safely as possible. In the event of the SMP issuing an abort command the UAV identifies the safest possible area to land in either from its current location, from a database of previously identified safe landing sites, or by contacting neighbouring UAVs. The safety management protocol is responsible for monitoring UAV location, health, connectivity and risks, for example from surrounding UAVs.

3.1 UAV location

Flying a small autonomous quad-rotor UAV over heavily populated areas currently presents an unacceptable risk of causing damage to property or, in extreme cases human fatalities. Whilst the envisaged initial application for the SUAAVE project is mountain search and rescue it is desirable to include a mechanism whereby areas which are known to be unsuitable for flying over can be avoided. One such example is a school which may be in close proximity to the operational area. The location of unsuitable areas for flying through are indicated within the SMP by specifying the corner points of a bounding box via a series of GPS coordinates. When the application layer sends a GPS waypoint it is verified against the unsuitable areas specified in the SMP and unsafe requests subsequently denied. This provision reduces the probability of causing damage to property and people however increases the complexity of the path planning algorithms used.

3.2 UAV health

The system health of the UAV can be influenced by many factors including operating and environmental conditions, for example decreased battery life due to wind or loss of GPS signal due to the profile of the terrain. In a related SUAAVE publication [3] it is proposed that the UAV periodically checks for and diagnoses errors. The UAV passes through several states including:

1. Pre-Flight Bootstrap - This phase of operation ensures that the necessary communication links, GPS, and on-board sensors are functional. The successful execution of this phase is a prerequisite to flight.
2. In-Flight Self Diagnostics - During a flight the UAV periodically executes this phase to detect and diagnose errors.
3. Operation - The operation phase is the most common state of the UAV during which the UAV executes its assigned mission.

4. Recover - In the event that an error is encountered the UAV will attempt to recover from that error, for example loss of a communication link may be resolved by relocating within range of another UAV or the base station.
5. Abort - Should the UAV encounter an irrecoverable error then the safest course of action may be to land as soon as possible. In the event of an abort command being issued by the SMP or the human operator the UAV will attempt to land as safely as possible.

The relationship between each of these states is outlined in Figure 1.

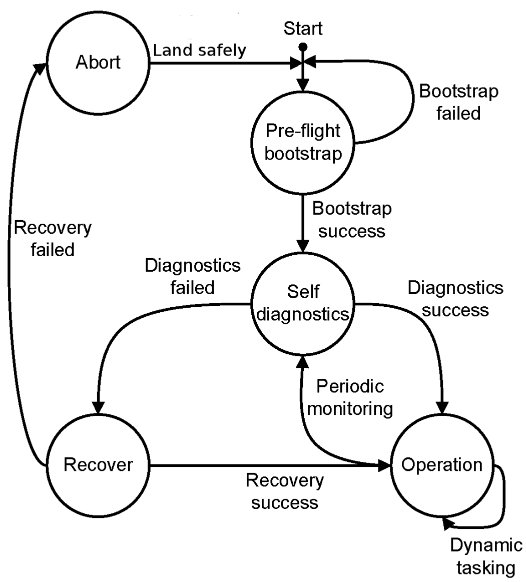

Fig. 1. State transition diagram for the phases of operation.

3.3 Maintaining connectivity

An important constraint imposed by the SMP is that the potential for connectivity between a UAV and the base station is maintained at all times. This may be either via direct communication or a multi-hop link between neighbouring UAVs. From a safety prospective this constraint is significant as it helps ensure that there is a human-in-the-loop at all times who can abort a mission or command a single UAV to land.

Balancing the limited flight time of the UAVs, the requirement of constant connectivity and the need to maximize information gain results in a project requirement of resource aware path planning algorithms. To achieve maximum information gain given the platform constraints the algorithm presented in [13] has been implemented and extended by incorporating two new features. Firstly, the algorithm is modified to account for the changing communication range of the UAVs in response to environmental and topographic conditions. Secondly, a multi-hop routing protocol has been incorporated.

In the event of a loss of communication link the UAV will attempt to recover by relocating within range of other UAVs or the base station. Should this loss of communication link continue the SMP will switch to an abort state during which it will attempt to land the UAV as safely as possible.

3.4 Collision avoidance

One potential hazard which is especially pertinent to UAVs operating as members of a swarm is that of mid-air collisions. Within the SUAAVE project an approach to multi-UAV collision detection using the IEEE 802.11 wireless networking protocol has been designed and implemented. In this work the received signal strength between UAVs is used to estimate their distance. The sampling rate is dynamically based on the speed of the UAV broadcasting the signal. The distance between two UAVs is estimated assuming ideal propagation conditions and that there is a clear line-of-sight path between the transmitter and the receiver.

As the UAVs are operating as members of a swarm it is desirable that they are aware of the position of other UAVs which may only be accessible via a multi-hop connection. This knowledge enables UAVs to pre-emptively adjust their path to avoid breaching the safe operating distance threshold. One of the constraints placed upon the collision avoidance strategy is that it should not depend on GPS. In the absence of GPS the location of a UAV can be estimated from three nodes whose positions are known. Once this location is known the distance, $D(i,j)$ between UAV$_i$ with coordinates (X_i, Y_i, Z_i) and UAV$_j$ with coordinates (X_j, Y_j, Z_j) is estimated using the Euclidean distance measure,

$$D(i,j) = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2 + (Z_i - Z_j)^2} \tag{1}$$

This distance is stored in a dynamically updated table (Table 1) along with a unique UAV identifier, timestamp and coordinates. The table is updated with new information upon receiving a "Coords" message from a neighbouring UAV.

Table 1. Stored attributes of neighbouring UAVs

UAV name	**Timestamp**	**Coordinates**	**Distance**
UAV1	T_1	(X_1, Y_1, Z_1)	D_1
...	...	...	...
UAVn	T_n	(X_n, Y_n, Z_n)	D_n

The safe operating distance threshold refers to the minimum allowable distance between UAVs and is dynamically changed based on the speed of the UAV and number of neighbours. A breach of this safe operating distance threshold between two UAVs may be the result of operating conditions, for example wind, or a hardware error, for example GPS inaccuracies. Therefore, in this initial work and until robust see-and-avoid and sense-and-avoid technologies are available the UAV is issued with an abort command.

4 Detection of landing sites

In the event of receiving an abort command it is not sufficient to assume that the area directly beneath the UAV is suitable for landing. Furthermore it cannot be assumed that the UAV has the required resources to safely navigate to the base station. It is therefore desirable to provide a means of detecting a safe landing area which considers the surrounding terrain and the available resources of the UAV. This section and subsequent subsections discuss the detection of a landing site from a colour aerial image captured from the UAV. An overview of the processes used for the detection and storage of landing sites can be found in Fig. 2.

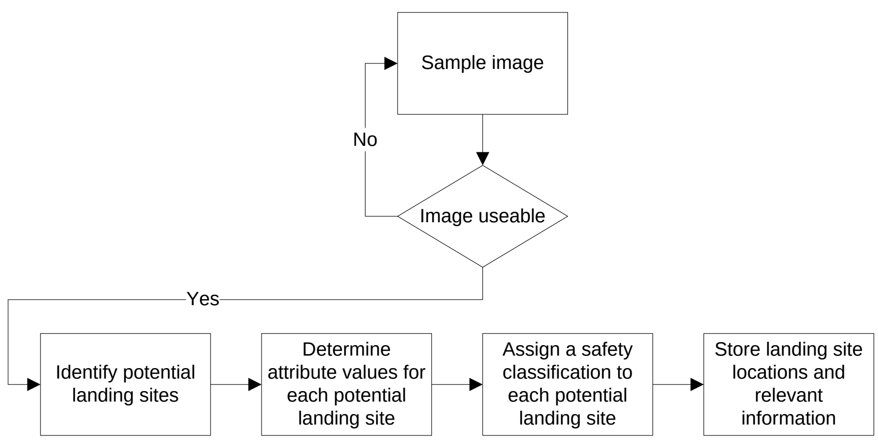

Fig. 2. Safe landing site detection overview

Sample image and test for quality The first stage in the safe landing site detection algorithm is to sample a frame from the live video stream. To avoid needlessly expending processing time by executing the algorithm on previously seen images this sampling rate is related to the altitude and velocity of the UAV. In this initial work an assumption is made that the UAV is travelling in a forward motion and is located at the centre of the image. Furthermore, the attitude of the UAV is not taken into account. The image sampling rate, S from the video stream is therefore,

$$S = (I_y/2 * R)/V \tag{2}$$

where I_y is the resolution of image I along the y axis, R is the ground pixel resolution and V is the velocity of the UAV estimated from GPS and IMU data. The ground pixel resolution, R, refers to the size of each pixel and can be calculated using [14],

$$R = (AW * H)/(FL * I_x) \tag{3}$$

where AW is the sensor array width in mm, H is the height above ground level, FL is the lens focal length in mm and I_x is the width of the image.

Identify potential landing sites The sampled image is then analysed to identify regions which are of a suitable size and shape for landing. An edge detection operator is executed on the sampled image to identify object boundaries. In comparison to many image segmentation techniques edge detection in an unconstrained environment is relatively computationally inexpensive and provides reasonable results. However an assumption is made that object boundaries exhibit a steep change in intensity gradient. Currently a Canny edge detector [15] is used to identify object boundaries. This operator requires three parameters, σ which denotes the standard deviation of the Gaussian filter, a low threshold for high edge sensitivity and a high threshold for low edge sensitivity. These thresholds are currently determined empirically and are statically defined however, in future work it is planned that the parameters will be dynamically adjusted according to altitude. The resulting image is then dilated to increase the size of object boundaries and to close small gaps. The motivation behind this step is to provide a margin of error when performing the actual landing.

Following edge detection and dilation areas which are of a suitable size for landing in are identified. The Ascending Technologies Hummingbird UAV is approximately $0.5m^2$ in size which, depending on the altitude of the UAV corresponds to varying numbers of pixels in the input image. The process of identifying potential landing sites can be represented by the following pseudo code:

```
begin
    execute Canny edge detector on input image, i
    dilate detected edges by 1.5m
    for each group of pixels, p in input image, i
        analyse a rectangular area corresponding to 20m^2 surrounding p
            if the area does not contain edges
                set p as a potential landing site
            end
        end
    for all potential landing sites, p_i
        for all potential landing sites, p_j
            if p_i is adjacent to p_j
                merge
            end
        end
```

end
assign a unique ID to each potential landing site
end

Determine attribute values The previous stages of edge detection, dilation and identification of areas of suitable size results in a set of potential landing sites. The suitability of these potential landing sites is determined by a number of factors including terrain classification and roughness.

Currently a Maximum Likelihood Classifier (MLC) is used for the classification of terrain. This classifier requires training data from which class spectral signatures are estimated. The MLC estimates the probability of a pixel represented by a vector of spectral values, $\mathbf{x}$ belonging to class ω_i and is given as [16],

$$p(\mathbf{x}|\omega_i) = (2\pi)^{-1/2}|\mathbf{\Sigma}_i|^{-1/2}exp\{-\frac{1}{2}(\mathbf{x}-\mathbf{m}_i)^t\mathbf{\Sigma}_i^{-1}(\mathbf{x}-\mathbf{m}_i)\}, \tag{4}$$

where $\mathbf{m}_i$ is the mean spectral values and $\mathbf{\Sigma}_i$ is the covariance matrix for each class i.

Intuitively different terrain types have varying degrees of suitability for landing in. Current classes used in mountainous terrain are grass, gorse, rock, trees and water. These classes are assigned a numeric suitability measure in the range [0..1] by a human expert familiar with the operational area. This suitability measure is used to determine a fuzzy classification of unsuitable, risky or suitable (Figure 3a).

In aerial images of many rural scenarios man-made structures typically exhibit a high greyscale contrast deviation in comparison to the surrounding terrain. Landing a UAV near these structures presents a higher risk of damaging property and possibly harming people. Therefore the greyscale intensity deviation of each area surrounding a potential landing site is analysed and assigned a fuzzy classification of low, medium or high (Figure 3b). In the event of a fuzzy classification of high the potential landing site is discounted as unsafe. In future work it is planned that man-made structures will be more robustly detected by fusing map information with the aerial image sensor data.

Potential landing sites which are exceptionally rough, for example areas which are very stony represent a risk to the safety of the UAV and its payload. As with man-made structures these areas typically exhibit relatively high greyscale intensity deviation and so this measure is used as an estimate of roughness. A fuzzy classification of smooth, rough and very rough is used to describe the roughness property (Figure 3c).

The greyscale intensity deviation of a landing sites neighbourhood and the landing sites roughness is calculated using [17]:

$$I_m = \frac{\sum_{i,j\in r} I_{i,j}}{N*M}, V = \sqrt{\frac{\sum_{i,j\in r}(I_m - I_{i,j})^2}{N*M}} \tag{5}$$

where I_m is the average pixel intensity within the region, r is the region under consideration, i, j is the location of the pixel in the image, I is pixel intensity, $N*M$ is the size of region r and V is the standard deviation.

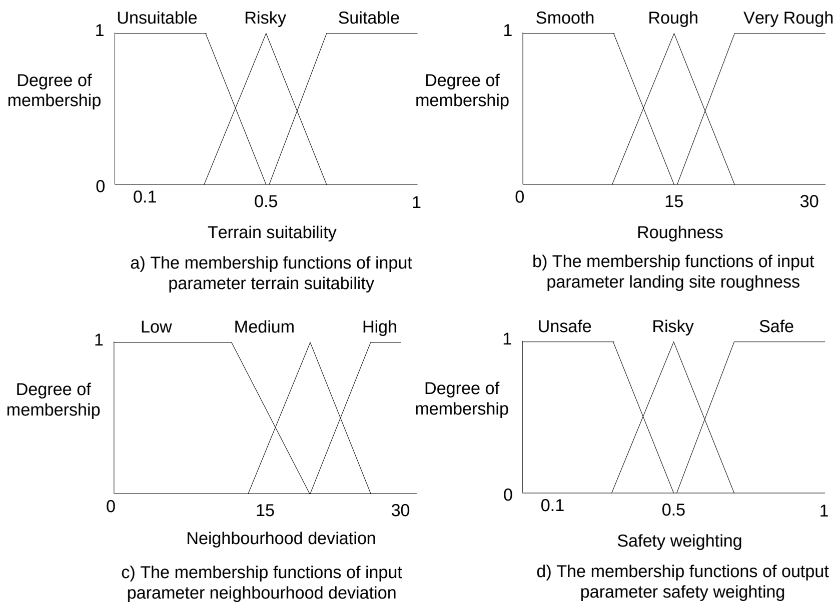

Fig. 3. The membership functions of fuzzy logic parameters

Landing site safety classification The fuzzy input parameters of terrain suitability, neighbourhood deviation and roughness are aggregated using a series of rules to produce a fuzzy output (Figure 3d), for example *if terrain is suitable and neighbourhood deviation is low and roughness is smooth then landing site = safe*. These rules are generated based on expert knowledge which is captured during a training phase prior to deployment. The centroid defuzzification method is used to provide a crisp numeric value for safety weighting.

Storage of previously classified landing sites It is desirable to store all previously seen landing sites for future use. Attributes of landing sites which are stored are outlined in Table 2.

Table 2. Stored attributes of classified landing sites

Attribute	Description
ID	Primary key - Used to uniquely identify each landing site
Time	Each landing site is time-stamped
Latitude/Longitude	Used to estimate attainability
Grid reference	The corner coordinates in the image of the landing site
Safety weighting	The numeric safety weighting of each landing site

These attributes enable the UAV to locate a previously identified landing site in the event of receiving an abort command from the SMP in an area which is unsuitable for landing in. A time-stamp on each landing site may be used as an indication of the safety classification accuracy which in a dynamic environment, for example farmland may change over time. The database is updated when a new landing site is identified. Many other processes such as path planning are executed in parallel with the safety module which results in processing and storage constraints. Under certain conditions it may therefore be feasible to only store landing sites with a safety weighting above a given threshold.

During the course of a mission a large number of classified landing sites may be accumulated. The potential usefulness of these landing sites may decrease over time and with distance from the UAV's location. To avoid sorting through a large number of unattainable landing sites in the event of an emergency the database is periodically pruned of such sites.

5 Choosing a landing site

In the event of the SMP issuing an abort command the UAV will consider the state of its resources and the suitability of surrounding and previously sensed terrain to choose a suitable landing site. An overview of the decisions taken by the UAV are outlined in Figure 4 and are discussed in the subsequent subsections.

Attainability A key attribute when choosing a landing site is its attainability which is determined by remaining battery life and distance from the UAV's current position. The Ascending Technologies Hummingbird UAV used in the SUAAVE project has a battery life of approximately 23 minutes or 12 minutes with a 200g payload. However, this can be significantly influenced by environmental conditions such as wind.

In the absence of models which characterize the effects of specific flight manoeuvres and environmental conditions upon the platforms battery, the travelled distance and current battery voltage may be used as an estimate of the required power per m of the UAV.

Given an estimate of the required power per m of the UAV the potential attainability of a landing site can be determined by:

$$R = C - D * P \tag{6}$$

where R is the remaining battery life in volts (v) after navigating to the landing site, C is the current battery life in v, D is the distance of the landing site from the UAV's position in m and P is the required battery power in v per m.

The required power to navigate to a landing site is estimated as a percentage of remaining battery life. A landing site is considered unattainable if it requires more than 75% of the remaining battery life to navigate to that area. Therefore, in emergency situations the UAV reserves 25% of battery life to ensure that it has sufficient power to perform a controlled descent and, if possible transmit its location following an emergency landing.

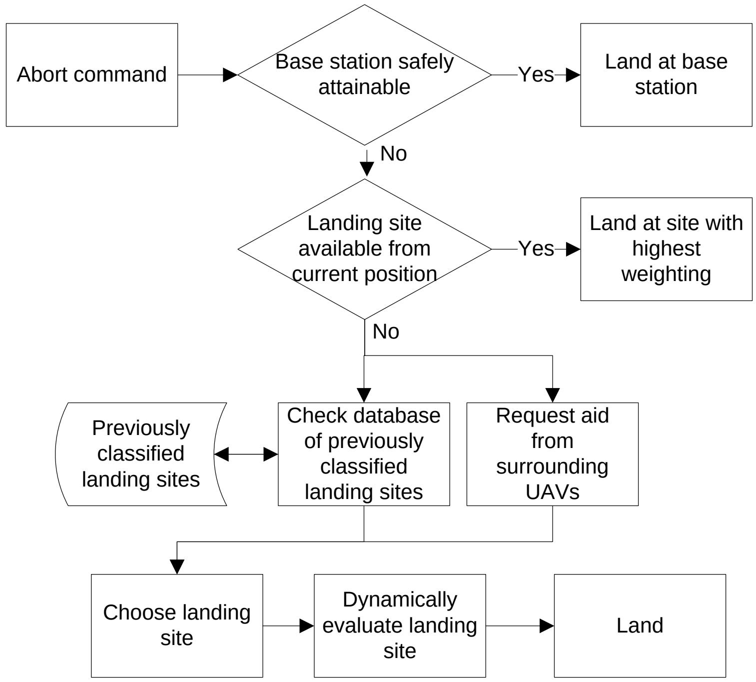

Fig. 4. Safe landing system overview

Part of the future work within the SUAAVE project will involve characterisation of the UAV platform. This will enable the impact of environmental conditions and specific flight manoeuvres upon battery life to be modelled. Furthermore, the power required by the UAV to perform a controlled descent and transmit its location can be estimated from these models enabling the attainability thresholds of a landing site to be more accurately defined.

Neighbouring landing sites It is possible that a landing site which appears suitable for landing in from a high altitude may, upon closer inspection contain hazards. Preference is therefore given to landing sites which have surrounding areas which are suitable for landing in. Therefore in the event of a chosen landing site containing hazards, alternative, attainable landing sites are available.

5.1 Base station

In the first instance the UAV will assess if it has sufficient battery life to safely navigate to the base station. Landing at the base station enables easy recovery of the UAV which is an important advantage given that a single operator may be responsible for an entire swarm.

5.2 Current location

In the event of the base station being unattainable the UAV will attempt to locate a landing site from its current location using aerial image data captured from the onboard camera. The sequence of events executed in this scenario are similar to those outlined in Figure 2 however, as opposed to storing landing site locations a decision is made as to the most suitable landing site from the input image.

The distance of landing sites detected from the UAV's current location is estimated by calculating the Euclidean distance from the UAV's current position to the centre of each landing site. This distance is used in conjunction with remaining battery life to estimate attainability.

5.3 Check database

In the event of no suitable landing site being available from the current location the UAV will query the database of previously classified landing sites. This database contains the unique id, longitude/latitude position, safety classification and time stamp for each landing site. The distance, d from the UAV's current position to the location of the landing site is calculated using the haversine formula [18],

$$d = Rc \tag{7}$$

where R is the Earth's radius in m and c is calculated as,

$$\Delta lat = lat_2 - lat_1, \Delta long = long_2 - long_1, \tag{8}$$

$$a = \sin^2\left(\frac{\Delta lat}{2}\right) + \cos(lat_1)cos(lat_2)\sin^2\left(\frac{\Delta long}{2}\right), \tag{9}$$

$$c = 2atan2(\sqrt{a}, \sqrt{(1-a)}) \tag{10}$$

The fields in the database are subsequently sorted into ascending order by distance from the UAV's current position and are compared against any landing sites which are detected by neighbouring UAVs.

5.4 Neighbouring UAVs

One of the requirements placed upon the UAVs by the SMP is that the potential for connectivity is maintained at all times. Therefore in the event of a member of the swarm performing a forced landing for reasons other than connectivity problems it is possible that a neighbouring UAV may be able to detect a landing site which has not been previously identified and stored by the UAV. If a neighbouring UAV can identify a safe landing site it will transmit the location of that site along with its associated safety weighting and number of neighbouring landing sites via 802.11.

5.5 Landing

The result of searching through the safe landing site database and requesting aid from surrounding UAVs is a list of attainable safe landing sites and their associated attributes. In this initial work the safe landing site with the greatest number of attainable, neighbouring safe landing sites is chosen. As the UAV descends it is possible that at lower altitudes a hazard may be identified in the landing site. Therefore, the chosen landing site is dynamically evaluated. In the event of the landing site containing hazards a neighbouring landing site is chosen.

A constraint placed upon the UAVs by the SMP is that connectivity with the base station must be maintained. This connectivity can be either directly between the UAV and the base station or via neighbouring UAVs using a multi-hop routing protocol. In the event of a UAV performing an emergency landing the configuration of other swarm members will adapt to ensure that connectivity is maintained. A further constraint imposed by the SMP is with respect to the maximum allowable distance between swarm members. A possible scenario is where multiple UAVs attempt to land at the same landing site. It is therefore desirable that a UAV retains a portion of battery life to periodically transmit a "Coords" message to other swarm members. This will be used in conjunction with the collision avoidance module of the SMP to help decrease the risk of multiple UAVs landing in close proximity to each other.

In the example shown in Figure 5, 3 UAVs are dispatched to sense the environment in search for a missing person. Due to a GPS failure UAV1 navigates out of multi-hop communication range with the base station. As it cannot safely navigate to the base station without GPS UAV1 executes the safe landing site detection algorithm and determines that the ground directly beneath it is suitable for landing in. UAV1 subsequently lands and periodically transmits a "Coords" message notifying other UAVs of its presence should they fly within communication range.

6 Conclusions/Future work

In this position paper a safety management protocol which incorporates connectivity constraints, collision avoidance and safe landing site detection from aerial image data is presented. A novel algorithm is described for the detection, storage and subsequent choosing of safe landing sites. Preliminary results indicate potential in the approach used for the detection of landing sites.

In future work it is planned to validate and improve all components of the SMP based on experiments conducted on a Hummingbird quadrotor UAV. A further piece of future work will be characterization of the platform in varying environmental conditions which will enable the attainability components of the algorithm to be defined more accurately.

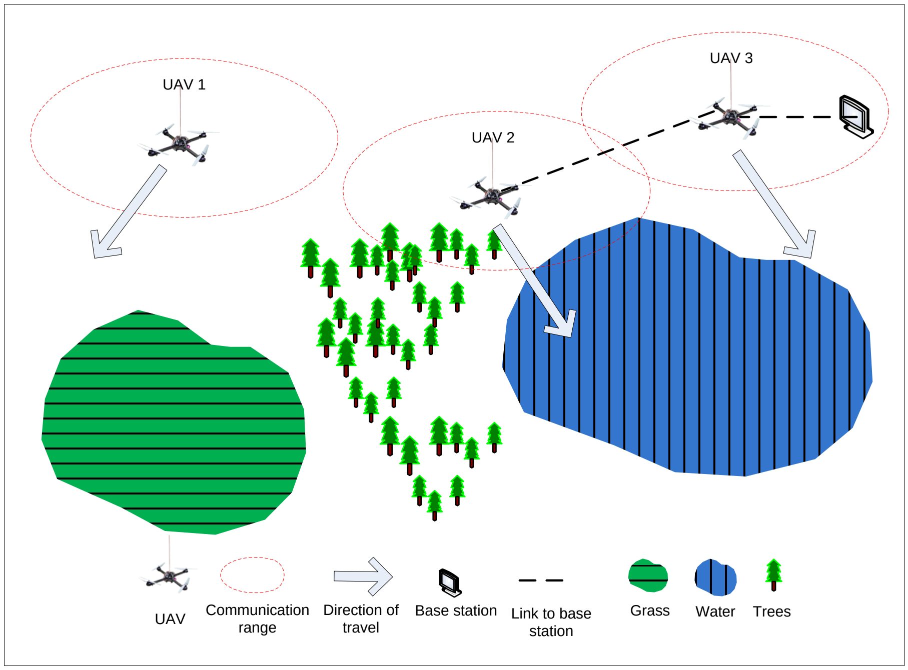

Fig. 5. Example scenario where an emergency safe landing is required

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